IDENTIFICATION OF THRESHOLD LEVELS FOR WARNER-BRATZLER SHEAR FORCE OF BEEF VALUE CUTS

A Thesis

by

LEEANN SITKA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2007

Major Subject: Animal Science

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Approved by:

Chair of Committee,	Jeffrey W. Savell
Committee Members,	Daniel S. Hale
	R. Daniel Lineberger
Head of Department,	Gary R. Acuff

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ABSTRACT

Identification of Threshold Levels for Warner-Bratzler Shear Force of Beef Value Cuts.

(August 2007)

LeeAnn Sitka, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Jeffrey W. Savell

This study was conducted to determine threshold levels for Warner-Bratzler shear (WBS) force of the beef value cuts. USDA Choice and USDA Select *M. biceps femoris, M. gluteus medius, M. infraspinatus, M. longissimus lumborum, M. rectus femoris, M. triceps brachii, and M. vastus lateralis* steaks were evaluated for palatability characteristics and tenderness acceptability by a consumer panel (n = 205). Steaks also were evaluated by WBS analysis. The relationship between consumer tenderness-like ratings and WBS was investigated through regression analysis. Threshold WBS levels could not be determined due to the low correlation between consumer tenderness ratings and WBS. Within a muscle, percent tenderness acceptability was determined for each of the tenderness-like ratings. After analyzing the consumer ratings, tenderness acceptability, and WBS values, it was apparent that there may not be a single WBS threshold value suitable for all muscles. Research indicates that there may be muscle-specific WBS threshold levels; these values were not established from this research.

DEDICATION

This thesis is dedicated to my family. My parents, Robert and Mary Lee, have given me constant support and unconditional love throughout my life. Thank you for believing in me and encouraging me to follow my dreams. To my sister, Kristin, brother-in-law, Eric and nephew, Rylan, thank you for reminding me of the important things in life. Kristin, you have always been a great role model and friend. We both know I would have been lost without you. Thank you so much for everything you have done for me. I love you all so much.

This is also dedicated to my fiancé, Josh, for your endless love and patience. Thank you for always having faith in me and giving me the encouragement I need. I love you very much.

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I thank the members serving on my thesis committee, Dr. Jeffrey Savell, Dr. Daniel Hale, and Dr. Daniel Lineberger. Without their encouragement and guidance, this project would not have been a success. Also, I thank Dr. Rhonda Miller for her continuous support throughout the project.

This project could not have been possible without the help of my fellow graduate students, Lyda Garcia, Ashley Haneklaus, Jarrett Hudek, Brad Kim, Megan Laster, Eric Metteauer, John David Nicholson, Robby Smith, and Kristin Voges. Their hard work and dedication was never failing throughout my graduate studies. I also thank the student workers for their assistance throughout the project: Keri Bagley, Haley Deitzel, Katie Leigh, Megan Maenius, and Will Wiederhold. In addition, I thank everyone else who assisted in the project: Teresa Aldredge, Gabriel Chmielewski, Erica Dickey, James Dillon, Katelyn Edwards, Kevin Hawks, Austin Lowder, and Margaret Schell. Furthermore, Ray Riley and the meat lab workers have made this possible through their cooperation and assistance. Finally, I thank my family and friends for their love and support. This project was a success because of the combined help of everyone mentioned above.

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CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

With the help of muscle profiling research (Von Seggern, Calkins, Johnson, Brickler, & Gwartney, 2005), the National Cattlemen's Beef Association established new beef value cuts developed from the underutilized muscles of the beef round and chuck. These newly developed cuts were designed to offer consumers a more consistent, convenient and affordable product and add value to the beef carcass. The beef value cuts are comprised of single-muscle beef cuts that each have their own unique qualities. These select muscles vary in tenderness, juiciness, and flavor.

Past studies investigated consumer tenderness thresholds (Miller, Carr, Ramsey, Crockett, & Hoover, 2001; Shackelford, Morgan, Cross, & Savell, 1991) and acceptability (Huffman, Miller, Hoover, Wu, Brittin, & Ramsey, 1996; Miller et al., 2001; Platter, Tatum, Belk, Chapman, Scanga, & Smith, 2003) of beef by analyzing the relationship between Warner-Bratzler shear (WBS) force values and sensory panel evaluations. However, these studies only examined this relationship for the *M. longissimus dorsi*. With so much variation found within the muscles of a beef carcass, it is probable that different threshold values and levels of acceptability exist for different muscles. Overall acceptability is influenced by tenderness, flavor and juiciness

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This thesis follows the style of *Meat Science*.

(Huffman et al., 1996; Miller et al., 1995a, 2001) and consumer perception of tenderness is thought to be influenced by flavor and juiciness (Miller et al., 1995a, 2001; Neely et al., 1998). Therefore, tenderness threshold values may reflect variation among muscles and result in different threshold levels for different muscles of the beef carcass.

According to the Beef Industry Long Range Plan 2010 (NCBA, 2006), one of the industry's priorities is to increase consumer beef demand, consumer satisfaction, and enhance carcass value. Determining threshold values for the beef value cuts will allow the industry to segment beef cuts according to tenderness classifications. This segmentation will allow the beef industry to reduce the variation in beef tenderness and charge a premium for more tender beef. Consumer studies found that consumers are willing to pay a premium for more tender beef (Boleman et al., 1997; Lusk, Fox, Schroeder, Mintert, & Koohmaraie, 2000; Miller et al., 2001; Shackelford, Wheeler, Meade, Reagan, Byrnes, & Koohmaraie, 2001). Miller et al. (2001) found that 78% of consumers would purchase steaks if the retailer guaranteed them to be tender. With the ability to purchase beef according to tenderness, consumers are more likely to have a positive eating experience that will result in an increase in consumer satisfaction and demand for beef.

In several consumer surveys, the greatest percentage of consumers listed tenderness as the most important sensory attribute of beef, the next highest percentage of consumers rated flavor as most important, and the lowest percentage rated juiciness as most important (Huffman et al., 1996; Miller, Huffman, Gilbert, Hammon, & Ramsey, 1995b; Platter et al., 2003). These results suggest that tenderness is a major contributing

factor to consumer satisfaction of beef. Therefore, understanding consumer perception of tenderness is important in order to achieve desired consumer acceptability of beef.

Studies show that consumers are able to distinguish differences in beef tenderness (Boleman et al., 1997; Huffman et al., 1996; Miller et al., 2001; Shackelford et al., 2001; Wheeler, Shackelford, & Koohmaraie, 2004). It has been confirmed that consumer panelists are an accurate and effective method of tenderness evaluation (Wheeler et al., 2004). In a study to determine the accuracy and repeatability of untrained laboratory consumer panelists, Wheeler et al. (2004) found that consumer panels were able to accurately detect differences in beef tenderness and were possibly as effective as trained panelist. Acceptability studies often examine the relationship between consumer tenderness ratings and overall acceptability (Huffman et al., 1996; Platter et al., 2003; Miller et al., 1995a, 2001). These studies reported that as tenderness ratings decreased consumer acceptability decreased. With consumers' ability to detect tenderness differences and the relationship between consumer tenderness ratings and overall acceptability, it is evident that tenderness thresholds could be established by analyzing the relationship between consumer ratings and objective measures of tenderness. Results from Platter et al. (2003) support this assumption by reporting a moderately high ($r = 0.63$) correlation between consumer tenderness ratings and WBS force values.

Shackelford et al. (1991) established threshold levels for WBS by running a regression analysis on WBS force values and trained sensory panel overall tenderness ratings of beef top loin steaks. Confidence levels for each threshold value were

developed to indicate the percent chance a steak within the threshold value will be rated "slightly tender" or higher. The resulting WBS thresholds were 4.6 kg, 3.9 kg and 3.2 kg with confidence levels of 50, 68 and 95%, respectively. When tested on data from the National Consumer Retail Beef Study (Savell et al., 1987), the 50 and 68% confidence levels were 88.6 and 74.3% accurate in predicting whether a steak would be rated "slightly tender" or less. These thresholds are considered benchmark values and have been used in succeeding studies to group steaks into tenderness categories according to their WBS force values (Belew, Brooks, McKenna, & Savell, 2003; Brooks et al., 2000; Morgan et al., 1991; Voges et al., 2006).

Threshold values similar to those published by Shackelford et al. (1991) have been created by analyzing the relationship of WBS and consumer acceptability. Platter et al. (2003) found that strip loin steaks with WBS values of 4.4 and 3.7kg would result in a 50 and 68% probability of acceptance. Miller et al. (2001) reported WBS threshold values of <3.0, 3.4, 4.0, 4.3, and >4.9 kg which resulted in consumer tenderness acceptability of 100, 99, 94, 86, and 25%, respectively. These WBS values can be used to group steaks according to the consumer acceptance desired.

In addition to finding a significant relationship between tenderness and overall acceptability, research shows that flavor and juiciness also have effects on consumer acceptability. In stepwise regression analyses of consumer sensory evaluations, studies show that flavor alone expressed the highest correlation with overall like and overall palatability (Goodson et al., 2002; Huffman et al., 1996). In addition to these two studies, several studies reported that flavor has a significant effect on overall consumer

acceptance of beef steaks (Miller et al., 1995a, 2001; Platter et al., 2003). A consumer threshold study found flavor and juiciness significantly influenced consumer tenderness ratings of beef strip loin steaks (Miller et al., 2001). Consumer acceptability studies suggest that consumers will accept slightly tough meat if the flavor and juiciness are acceptable (Huffman et al., 1996; Miller et al., 1995a, 2001). A high percentage of consumers considered steaks that received tenderness ratings of "slightly tough" to be acceptable. Although tenderness is the main focus when creating threshold values, these studies show that other sensory attributes may significantly influence threshold levels.

For this study, a laboratory consumer panel was chosen to evaluate the muscles for tenderness, flavor, juiciness, and overall like. A consumer panel provides insight on consumer preference (like/dislike), which is the main focus of this experiment. By conducting the consumer sensory analysis in the sensory laboratory as opposed to in-home, the research was performed in a controlled atmosphere which provided ideal testing conditions. The cooking method and degree of doneness was controlled in order to eliminate significant differences in ratings due to preparation. This study was designed to investigate the relationship between Warner-Bratzler shear force and consumer panel tenderness ratings of the beef value cuts in order to establish WBS threshold levels for each cut.

CHAPTER II

MATERIALS AND METHODS

2.1 Processing

USDA Choice and Select subprimals (n=560) were purchased from a commercial processing facility and shipped to the Rosenthal Meat Science and Technology Center. Specifications for all subprimals complied with Institutional Meat Purchase Specifications (IMPS) as described by USDA (1996) and NAMP (2003). The subprimals selected were Beef Chuck, Outside Shoulder (Clod) (IMPS #114); Beef Round, Tip (Knuckle), Peeled (IMPS #167A); Beef Round, Outside Round (Flat) (IMPS #171B); Beef Loin, Strip Loin, Boneless (IMPS #180); and Beef Loin, Top Sirloin Butt, Center-Cut, Boneless (IMPS #184B). Forty USDA Choice and forty USDA Select subprimals were obtained for each selected subprimal.

Before fabricating subprimals, temperature and pH (pH Star, SFK Technologies, Cedar Rapids, IA and Model IQ150, IQ Scientific Instruments, Inc., Carlsbad, CA, with model pH17-SS probe) were taken of each muscle. Beef shoulder clods, knuckles, and outside rounds were fabricated according to the NCBA (2001) Beef Value Cuts guidelines. The *M. infraspinatus* and *M. triceps brachii* were separated from the beef shoulder clods. All external fat and connective tissue was removed from the surface of the *M. infraspinatus*. The heavy internal connective tissue which runs the length of the muscle was removed. All external fat and connective tissue was removed from the surface of the *M. triceps brachii*, as well as the small side muscle. The *M. triceps*

brachii then was separated into the lateral head (shoulder top) and the long head (shoulder center). Only the long head of the *M. ticeps brachii* was utilized for this project. The *M. vastus lateralis* and *M. rectus femoris* were separated from the beef knuckles and completely denuded. The *M. biceps femoris* from the outside round was completely denuded. The *M. gluteus medius* from the top sirloin butt was completely denuded and the muscle was cut lengthwise along the seam parallel with the sciatic nerve to separate the larger portion of the *M. gluteus medius* from the smaller portion. Only the larger portion of the *M. gluteus medius* was used for the remainder of the research.

Following the processing of each muscle, three 2.54 cm thick steaks were cut from each muscle. Two steaks were assigned randomly for consumer sensory testing and one steak was assigned randomly for Warner-Bratzler shear (WBS) force determination. Objective color was measured using a Hunter Lab Mini-Scan® (Model MS XE Plus, Hunter Associates Laboratory, Inc., Reston, VA). Readings were taken from two random locations on one steak from each muscle. Steaks were vacuum packaged (Bivac® packaging machine, American Can Company™, American Lane, Greenwich, NJ) and aged at 1.0 $\pm$ 2.0ºC. Steaks were aged to a standardized 14 days from the subprimal's pack date. After aging, steaks were frozen at -10 ºC.

2.2 Consumer Panel

Consumers were recruited from Bryan/College Station, Texas by randomly calling residents listed in the local phone book. Consumers were screened through a questionnaire during the telephone recruitment. The majority of consumers selected were between the ages 22 and 65. Participants were also required to consume meat at least five times per week.

Before each consumer sensory analysis, steaks were thawed at 4ºC for 48 hours. Steaks were cooked according to the NCBA (2001) Beef Value Cuts cooking instructions. Steaks were cooked to an internal temperature of 32 ºC, turned and then cooked to an internal temperature of 63ºC on electric grills (Hamilton Beach Indoor/Outdoor Grill, Hamilton Beach/Proctor Silex, Inc., Southern Pines, NC). Internal temperature was monitored using Omega trendicators (Omega Engineering, Inc., Stamford, CT) fitted with a 0.02 cm diameter, iron-constantan Type-T thermocouple wire. Raw weights and cooked weights were recorded for each steak to determine cook loss. Steaks were covered with aluminum foil and held in an Alto-Shaam® (Halo Heat, Alto-Shaam Inc. Milw, WI, Model 750-TH-II) oven at 48.8 ºC until served.

Consumers (n=205) were given instructions on the proper way to fill out the ballots, and how to cleanse their palate between each sample. Consumers were seated in individual booths under red lights. Located in each booth were double distilled deionized water and unsalted Saltine™ crackers for the consumers to cleanse their palates between each sample. Before evaluating their first sample, consumers filled out a demographics survey.

Four consumers evaluated samples from each steak. The samples were prepared by cutting the steak across the grain into 1.27 cm cubes. Two cubes per sample were served to the panelists in random order. Each consumer panelist evaluated 14 samples using an 8-point scale. Samples were evaluated for overall like/dislike of the sample (1=dislike extremely; 8=like extremely), overall like/dislike of juiciness (1=dislike extremely; 8=like extremely), level of juiciness (1=extremely dry; 8=extremely juicy), overall like/dislike of tenderness (1=dislike extremely; 8=like extremely), level of tenderness (1=extremely tough; 8=extremely tender), overall like/dislike of flavor (1=dislike extremely; 8=like extremely), and level of flavor (1=extremely bland or no flavor; 8=extremely flavorful). Consumers also were asked if they thought the sample was acceptable or unacceptable in tenderness. Consumers were compensated US $30 for their participation.

2.3 Warner-Bratzler Shear Force Analysis

Steaks assigned for Warner-Bratzler Shear force analysis were thawed and cooked using the same methods as described for consumer sensory analysis. Weights were recorded before and after cooking to determine cook loss. Steaks were covered and allowed to cool over night in a cooler at 4ºC.

After cooling, six 1.27 cm cores were removed parallel to the muscle fiber orientation from each steak Each core was sheared perpendicular to the muscle fibers using a Universal Testing System Machine (United 5STM-500, Huntington Beach, CA), equipped with a 11.3 kg load cell and a Warner-Bratzler shear force attachment. The

peak force (N) required to shear each core was recorded, and the average of the six cores was used to determine WBS force for each steak.

2.4 Statistical Analysis

Data were analyzed as a 2 × 7 factorial arrangement where quality grade, muscle, and quality grade × muscle were defined as main effects. Interactions were included in the final model if $P < 0.05$. For consumer data, Box-Cox transformation was performed. It was determined that data were not normally distributed and were thus transformed. Order served and consumer were defined as blocks. Least squares means were calculated, and if effects were significant in the Analysis of Variance table, means were separated using the p-diff option at $P< 0.05$. Shear data were analyzed as previously defined except blocks were not included in the model. However, Box-Cox transformations were not performed. Additionally, final internal temperature was used as a covariate. However, it was not significant ($P > 0.05$) and was not included in the final model. Simple correlation, means, and standard deviation were determined using PROC CORR within a muscle. Within a muscle, consumer demographics and consumer attributes were calculated. Within a muscle, percent tenderness acceptability was calculated for each tenderness rating.

Regression equations within a muscle were calculated using consumer overall tenderness as a dependent variable and shear force and its squared and cubed component as independent variables. The effect of consumer and order were included in the regression equation. However, their inclusion was not significant and did not affect R^2

values. Ninety-five, 68, and 50 percent confidence intervals were generated for each regression equation. Within a muscle, shear force data for overall tenderness were categorized by tenderness ratings 1 through 4, 5 and 6, and 7 and 8. The means and standard deviations for Warner-Bratzler shear force of each category were calculated for each muscle.

CHAPTER III

RESULTS AND DISCUSSION

3.1 Consumer Sensory Evaluations

Consumer demographic information for panelists that participated in the consumer sensory evaluation is presented in Table 1. The participants' consumption of beef, poultry, pork and fish are reported in Table 2. The categories in this table are based on the number of times per week each protein source is consumed in-home and away from home.

Muscle × USDA quality grade was the only significant main effect interaction for consumer sensory ratings ($P = 0.0082$). Least squares means for muscle × USDA quality grade effect on consumer sensory attributes are presented in Table 3. The USDA Choice *M. longissimus lumborum* received the highest ratings for overall like, however, it was not different ($P > 0.05$) from USDA Choice and Select *M. infraspinatus* and USDA Select *M. longissimus lumborum.* The USDA Select *M. biceps femoris* received the lowest ($P < 0.05$) consumer ratings for overall like. For juiciness like, the USDA Choice and Select *M. infraspinatus* received the highest ($P < 0.05$) consumer ratings and the USDA Choice and Select *M. vastus lateralis* along with the USDA Select *M. biceps femoris* received the lowest ($P < 0.05$) ratings. The USDA Choice and Select *M. infraspinatus* expressed the highest ($P < 0.05$) ratings for level of juiciness while the lowest ($P < 0.05$) ratings were given to the USDA Select *M. vastus lateralis*. The USDA Choice and Select *M. infraspinatus* and the USDA Select *M longissimus lumborum*

received the highest ($P < 0.05$) ratings for tenderness like. The muscle rated as the least desirable ($P < 0.05$) in tenderness was the *M. biceps femoris*. For level of tenderness, the USDA Choice and Select *M. infraspinatus* were rated highest ($P < 0.05$) and the USDA Select *M. biceps femoris* was given the lowest ($P < 0.05$) rating. The highest ($P < 0.05$) ratings for flavor like were designated to the USDA Choice and Select *M. infraspinatus* and *M. longissimus lumborum*. The lowest ($P < 0.05$) ratings for flavor like were given to the USDA Select *M. vastus lateralis* and *M. biceps femoris*.

Overall, the USDA Choice and Select *M. longissimus lumborum* and *M. infraspinatus* ranked high for all sensory attributes, whereas the USDA Choice and Select *M. vastus lateralis* and *M. biceps femoris* ranked low. The USDA Choice and Select *M. gluteus medius*, *M. rectus femoris*, and *M triceps brachii* tended to be intermediate for all sensory attributes.

Table 1
Demographic background of consumers that participated in consumer sensory panels

Item	n	%
	205	
Age, yr		
≤21	18	8.8
22-29	78	38.1
30-39	38	18.5
40-49	28	13.7
50-59	26	12.7
≥60	17	8.3
Income, US $		
<20,000	81	39.9
20,000-29,000	14	6.9
30,000-39,000	22	10.8
40,000-49,000	16	7.9
50,000-59,000	14	6.9
≥60,000	56	27.6
Gender		
Male	95	46.3
Female	110	53.7
Working Status		
Not employed	34	16.6
Full-time	81	39.5
Part-time	42	20.5
Student	48	23.4
Ethnicity		
Caucasian	172	84.3
Black	7	3.4
Hispanic	6	2.9
American Indian	2	1.0
Asian or Pacific Islander	17	8.3
Household Size		
1	32	15.6
2	80	39.0
3	44	21.5
4	27	13.2
5	18	8.8
≥6	4	2.0
Preferred degree of doneness		
Rare	9	4.3
Medium Rare	68	33.5
Medium	49	24.1
Medium Well	55	27.1
Well Done	22	10.8

Table 2
Beef, poultry, pork, and fish consumption of consumers that participated in consumer sensory panels

Type of Consumption	Times consumed per week, % (n)					
	Never	1	2	3	4	≥5
Meat						
In-home	1.0% (2)	5.4% (11)	9.9% (20)	16.3% (33)	21.7% (44)	45.8% (93)
Away from home	7.1% (14)	21.7% (43)	28.3% (56)	24.2% (48)	7.1% (14)	11.6% (23)
Beef						
In-home	2.5% (5)	13.8% (28)	24.6% (50)	34.0% (69)	15.8% (32)	9.4% (19)
Away from home	8.3% (16)	31.6% (61)	27.5% (53)	16.6% (32)	9.8% (19)	6.2% (12)
Poultry						
In-home	6.4% (13)	25.1% (51)	35.0% (71)	22.2% (45)	3.9% (8)	7.4% (15)
Away from home	23.8% (46)	40.9% (79)	22.8% (44)	10.4% (20)	1.0% (2)	1.0% (2)
Pork						
In-home	27.1% (55)	40.9% (83)	18.7% (38)	9.4% (19)	1.5% (3)	2.5% (5)
Away from home	68.6% (131)	20.4% (39)	7.9% (15)	2.6% (5)	0.5% (1)	0.0% (0)
Fish						
In-home	42.3% (85)	35.8% (72)	14.9% (30)	4.5% (9)	2.0% (4)	0.5% (1)
Away from home	57.4% (109)	33.7% (64)	5.8% (11)	2.6% (5)	0.5% (1)	0.0% (0)

Table 3
Least squares means for muscle × USDA quality grade effect on consumer sensory attributes

Muscle	Overall like[a]	Juiciness like[a]	Level of Juiciness[a]	Tenderness like[a]	Level of Tenderness[a]	Flavor like[a]	Level of Flavor[a]
Choice							
M. biceps femoris	4.5d	5.5ef	5.6d	4.2f	4.1g	4.8ef	4.8
M. gluteus medius	4.9c	5.3gh	5.2ef	4.9e	4.9ef	4.9de	5.0
M. infraspinatus	5.7ab	6.3ab	6.5a	6.4a	6.7a	5.2abc	5.4
M. longissimus lumborum	5.9a	6.1bc	6.0b	6.0bc	5.9bc	5.5a	5.3
M. rectus femoris	5.5b	5.8de	5.8bcd	5.7c	5.7c	5.2bcd	5.1
M. triceps brachii	5.2c	5.8d	5.9bc	5.1de	5.1de	5.0cde	5.0
M. vastus lateralis	4.6d	5.0hi	5.0fg	4.2f	4.2g	4.5g	4.4
Select							
M. biceps femoris	3.9e	4.8i	4.9g	3.4g	3.3h	4.2gh	4.4
M. gluteus medius	5.0c	5.3fg	5.3e	4.9e	4.7f	4.9de	4.9
M. infraspinatus	5.8ab	6.4a	6.6a	6.4a	6.6a	5.3ab	5.3
M. longissimus lumborum	5.8ab	5.9cd	5.8cd	6.2ab	6.2b	5.3ab	5.3
M. rectus femoris	4.9c	5.4fg	5.3e	5.3d	5.3d	4.5fg	4.6
M. triceps brachii	5.0c	5.8de	5.7cd	5.2d	4.9def	4.8e	4.9
M. vastus lateralis	4.3d	4.7i	4.6h	4.2f	4.2g	4.0h	4.2
P-value	0.0082	0.0007	0.0002	<0.0001	0.0002	0.0016	0.2308
RMSE	1.9592	3.8418	3.8489	2.1108	2.0379	1.5393	1.8455

Means within the same column lacking a common letter (a-i) differ ($P < 0.05$).
[a] 8=like extremely, extremely juicy, extremely tender, and extremely flavorful; 1=dislike extremely, extremely dry, extremely tough, and extremely bland.

Within a muscle, percent tenderness acceptability was determined for each of the tenderness like ratings (Figures 1-7). For the *M. biceps femoris*, the tenderness acceptability generally decreased as the tenderness like ratings decreased (Figure 1). The largest decrease in tenderness acceptability occurred between ratings 5 and 4 with a percent tenderness acceptability decrease of 83.64 to 44.44%. For the *M. gluteus medius*, the largest decrease in tenderness acceptability occurred between ratings 4 and 3 with a decrease in percent acceptability of 75.86 to 40.32% (Figure 2). The *M. infraspinatus* had high acceptability for tenderness ratings 4 through 8 with percentages greater than 90% for each rating (Figure 3). The drop between tenderness ratings 4 and 3 was 96.15 to 66.67%. The *M. longissimus lumborum* showed the largest drop in acceptability between tenderness ratings 4 and 3 (Figure 4). The tenderness acceptability for these ratings dropped from 86.96 to 50.00%. The *M. rectus femoris* tenderness acceptability typically decreased as the tenderness ratings decreased (Figure 5). Tenderness ratings 5, 4, and 3 received 87.76, 72.00, and 51.16% tenderness acceptability ratings. The *M. triceps brachii* showed the largest decrease in tenderness acceptability between tenderness ratings 4 and 3 with a decrease of 72.22 to 40.00% (Figure 6). The *M. vastus lateralis* showed a decrease in tenderness acceptability of 90.70 to 64.91% at tenderness ratings 5 and 4 (Figure 7).

For all muscles, the tenderness acceptability was relatively high for tenderness ratings 5 through 8. However, several muscles displayed a high percentage of tenderness acceptability for tenderness rating 4. These findings are similar to past consumer studies that examined tenderness acceptability (Huffman et al., 1996; Miller et

al., 1995a, 2001). Both Huffman et al. (1996) and Miller et al. (1995a) reported the largest decrease in tenderness acceptability occurred between tenderness ratings 3 and 4 on an 8 point scale. In a consumer threshold study, Miller et al. (2001) found that the transition between tender to tough beef occurred at tenderness ratings 5 and 4 where the acceptability decreased from 86 to 59%. The high acceptability at tenderness rating 4 of some muscles suggests that muscle specific attributes other than tenderness may influence the tenderness acceptability of a steak.

Simple correlation coefficients of consumer sensory attributes for the *M. biceps femoris* showed a strong relationship between all sensory attributes (Table 4). All sensory attribute correlations were significant ($P < 0.0001$). Tenderness like was the sensory attribute that was the most highly correlated to overall like with an $r = 0.80$. All sensory attributes expressed significantly high correlations to overall like ($P < 0.0001$) with level of tenderness, flavor like, juiciness like, level of flavor and level of juiciness having r values of 0.75, 0.72, 0.65, 0.64 and 0.56, respectively. Flavor like and juiciness like were highly correlated to tenderness like with $r = 0.60$.

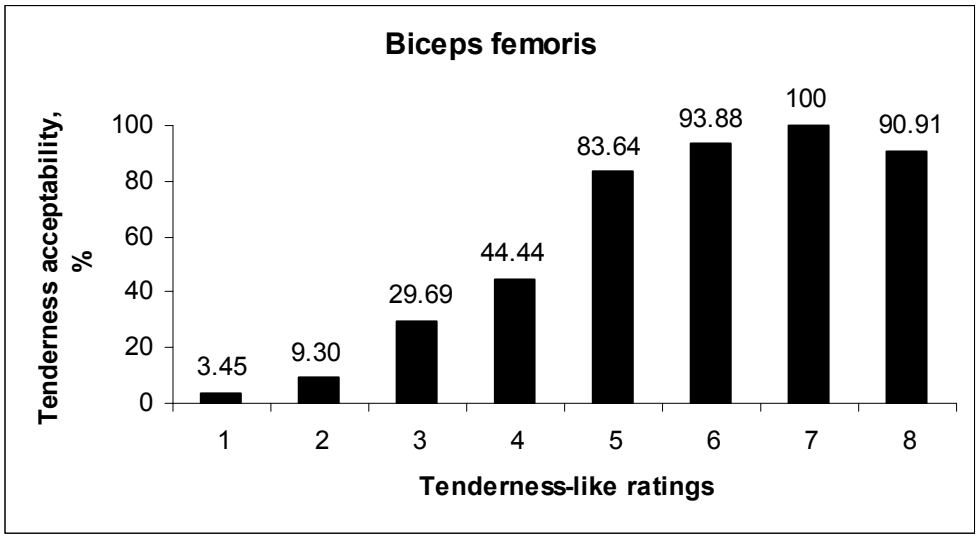

Figure 1. Percentage of samples evaluated at each of the tenderness-like rating considered acceptable in tenderness by consumers for *M. biceps femoris*

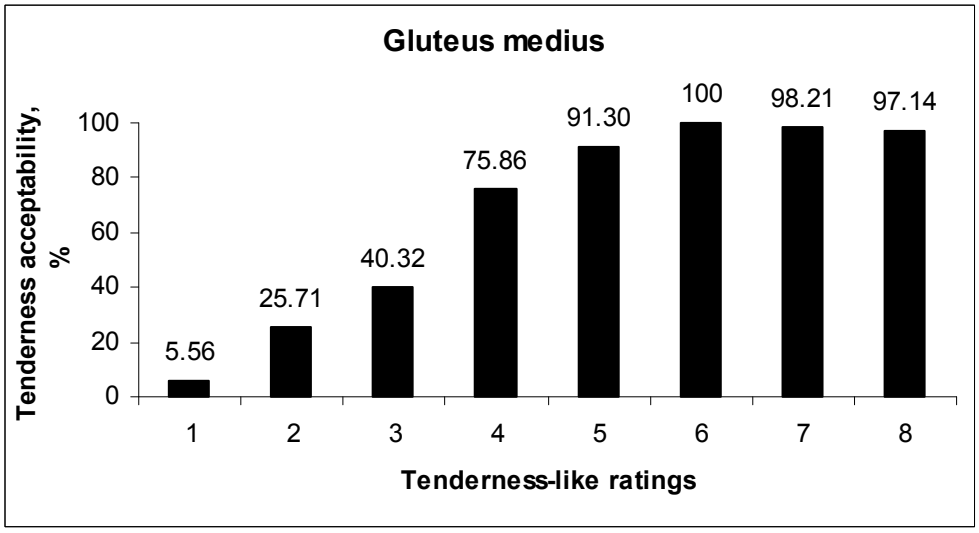

Figure 2. Percentage of samples evaluated at each of the tenderness-like rating considered acceptable in tenderness by consumers for *M. gluteus medius*

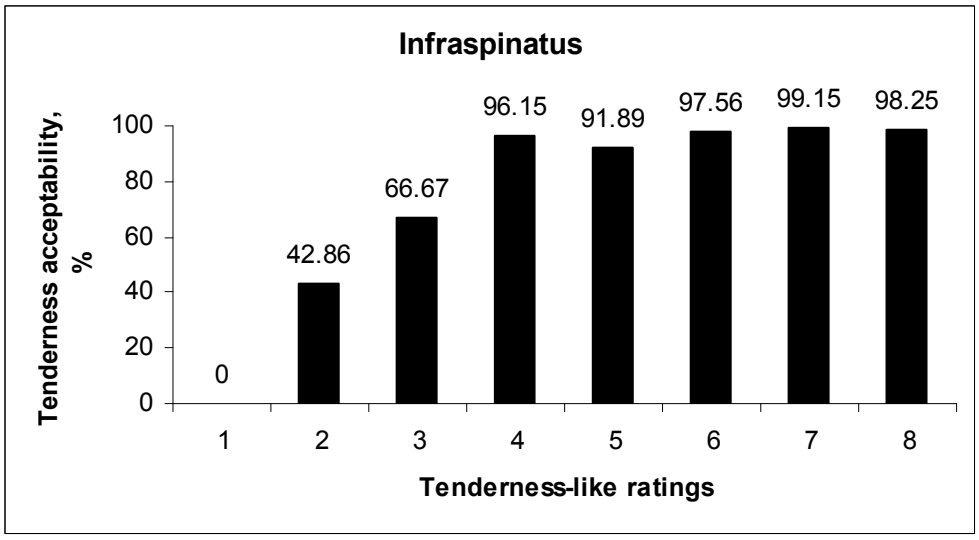

Figure 3. Percentage of samples evaluated at each of the tenderness-like rating considered acceptable in tenderness by consumers for *M. infraspinatus*

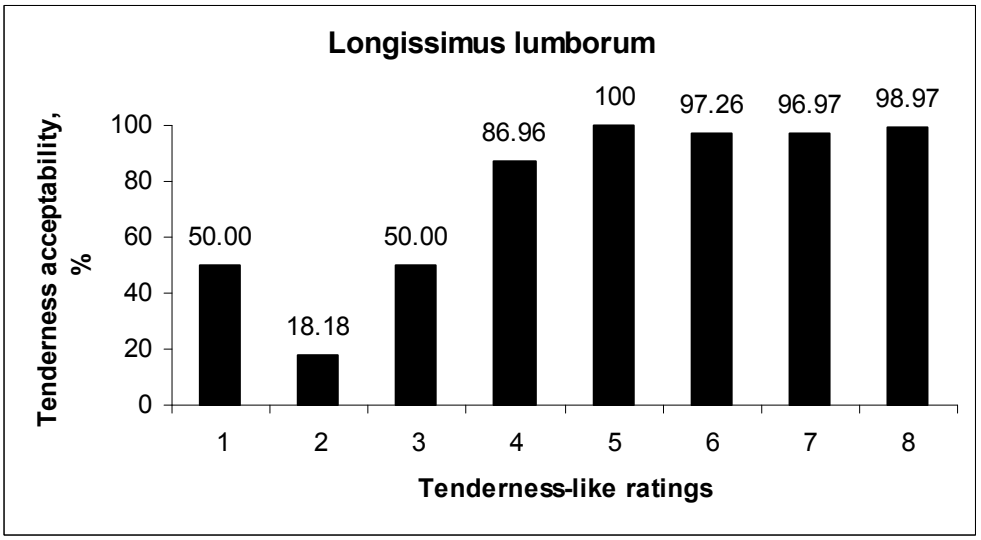

Figure 4. Percentage of samples evaluated at each of the tenderness-like rating considered acceptable in tenderness by consumers for *M. longissimus lumborum*

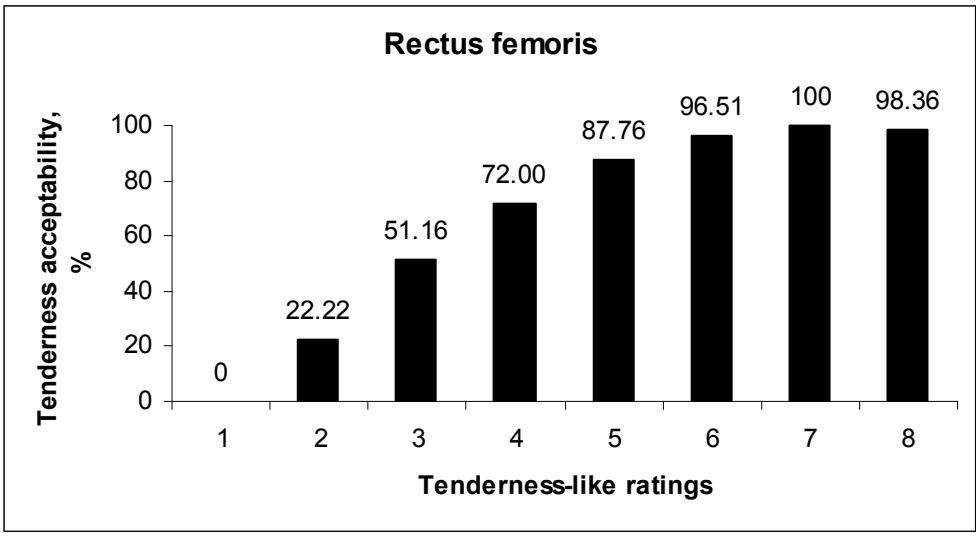

Figure 5. Percentage of samples evaluated at each of the tenderness-like rating considered acceptable in tenderness by consumers for *M. rectus femoris*

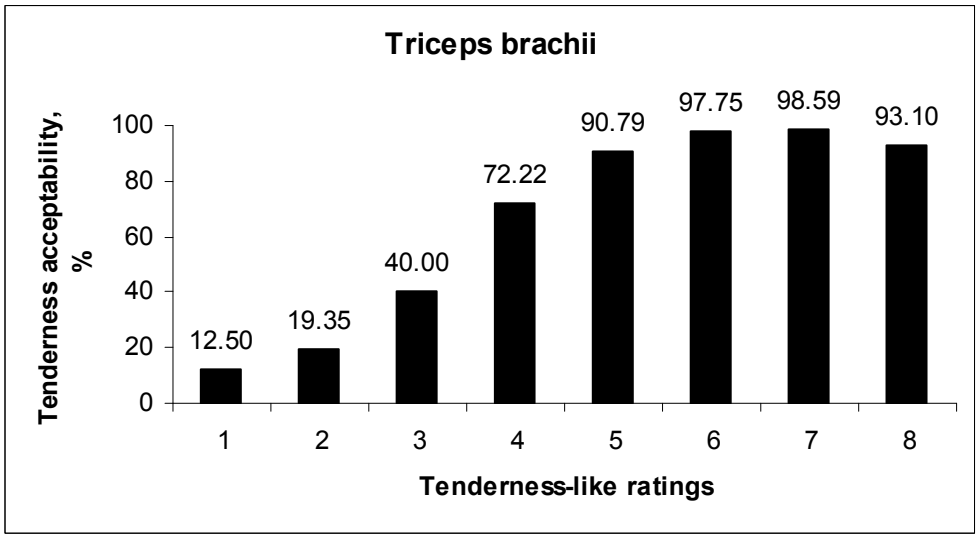

Figure 6. Percentage of samples evaluated at each of the tenderness-like rating considered acceptable in tenderness by consumers for *M. triceps brachii*

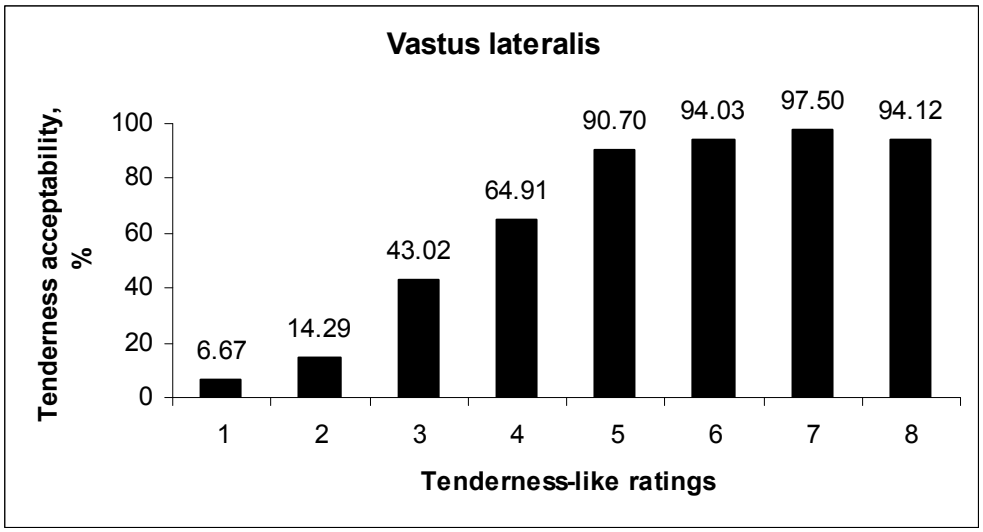

Figure 7. Percentage of samples evaluated at each of the tenderness-like rating considered acceptable in tenderness by consumers for *M. vastus lateralis*

Table 4
Simple correlation coefficients of consumer sensory attributes for *M. biceps femoris*

Variable	Level of Flavor	Flavor like	Level of Tenderness	Tenderness like	Level of Juiciness	Juiciness like
Overall like	0.64	0.72	0.75	0.80	0.56	0.65
Juiciness like	0.59	0.60	0.55	0.60	0.88	
Level of Juiciness	0.58	0.54	0.53	0.50		
Tenderness like	0.52	0.60	0.86			
Level of Tenderness	0.53	0.53				
Flavor like	0.81					

***All correlation coefficients were significant ($P < 0.0001$).

Simple correlation coefficients of consumer sensory attributes for the *M. gluteus medius* were highly significant for all sensory attributes ($P < 0.0001$). These correlation coefficients are displayed in Table 5. All sensory traits displayed a high correlation to overall like with tenderness like having the highest r value of 0.79. The remaining attributes level of tenderness, flavor like, juiciness like, level of flavor and level of juiciness expressed r values of 0.73, 0.73, 0.73, 0.65 and 0.62, respectively. When correlated with tenderness like, juiciness like had an r = 0.66 while flavor like had an r = 0.60.

Simple correlation coefficients of consumer sensory attributes for the *M. infraspinatus* are presented in Table 6. All sensory attribute correlations were significant ($P < 0.0001$). Flavor like was the sensory trait most highly correlated to overall like with an r = 0.77. Juiciness like, tenderness like, level of flavor, level of tenderness, and level of juiciness displayed high correlations with overall like with r values of 0.69, 0.67, 0.64, 0.55 and 0.48, respectively. Tenderness like revealed a correlation of r = 0.61 with juiciness like and an r = 0.51 with flavor like.

Table 5
Simple correlation coefficients of consumer sensory attributes for *M. gluteus medius*

Variable	Level of Flavor	Flavor like	Level of Tenderness	Tenderness like	Level of Juiciness	Juiciness like
Overall like	0.65	0.73	0.73	0.79	0.62	0.73
Juiciness like	0.57	0.62	0.62	0.66	0.87	
Level of Juiciness	0.51	0.52	0.60	0.56		
Tenderness like	0.51	0.60	0.89			
Level of Tenderness	0.48	0.53				
Flavor like	0.88					

***All correlation coefficients were significant ($P < 0.0001$).

Table 6
Simple correlation coefficients of consumer sensory attributes for *M. infraspinatus*

Variable	Level of Flavor	Flavor like	Level of Tenderness	Tenderness like	Level of Juiciness	Juiciness like
Overall like	0.64	0.77	0.55	0.67	0.48	0.69
Juiciness like	0.54	0.58	0.55	0.61	0.76	
Level of Juiciness	0.45	0.43	0.58	0.46		
Tenderness like	0.46	0.51	0.74			
Level of Tenderness	0.46	0.46				
Flavor like	0.84					

***Simple correlation coefficient is significant ($P < 0.0001$).

Simple correlation coefficients of consumer sensory attributes for the *M. longissimus lumborum* showed a strong relationship between all sensory attributes (Table 7). All sensory attribute correlations were significant ($P < 0.0001$). With a correlation of r = 0.78, flavor like was the attribute with the highest correlation to overall like. In addition to flavor, tenderness like and juiciness like possessed strong correlations to overall like with r values of 0.72 and 0.70, respectively. The remaining attributes level of flavor, level of tenderness, and level of juiciness revealed r values of 0.68, 0.66 and 0.63, respectively. Tenderness like was highly correlated with both juiciness like (r = 0.64) and flavor like (r = 0.56).

Simple correlation coefficients of consumer sensory attributes for the *M. rectus femoris* are presented in Table 8. All correlations expressed a significantly strong relationship ($P<0.0001$). Flavor like was most highly correlated to overall like with an r = 0.79. However, all attributes displayed high correlations to overall like with juiciness like, tenderness like, level of tenderness, level of flavor, and level of juiciness resulting in r values of 0.74, 0.70, 0.68, 0.67, and 0.65, respectively. Juiciness like and tenderness like correlation was r = 0.62, while the correlation between flavor like and tenderness like was r = 0.59.

Table 7
Simple correlation coefficients of consumer sensory attributes for *M. longissimus lumborum*

Variable	Level of Flavor	Flavor like	Level of Tenderness	Tenderness like	Level of Juiciness	Juiciness like
Overall like	0.68	0.78	0.66	0.72	0.63	0.70
Juiciness like	0.59	0.58	0.61	0.64	0.88	
Level of Juiciness	0.57	0.51	0.62	0.57		
Tenderness like	0.52	0.56	0.88			
Level of Tenderness	0.52	0.49				
Flavor like	0.81					

***All correlation coefficients were significant ($P < 0.0001$).

Table 8
Simple correlation coefficients of consumer sensory attributes for *M. rectus femoris*

Variable	Level of Flavor	Flavor like	Level of Tenderness	Tenderness like	Level of Juiciness	Juiciness like
Overall like	0.67	0.79	0.68	0.70	0.65	0.74
Juiciness like	0.60	0.63	0.59	0.62	0.86	
Level of Juiciness	0.60	0.56	0.63	0.59		
Tenderness like	0.51	0.59	0.90			
Level of Tenderness	0.50	0.54				
Flavor like	0.84					

***All correlation coefficients were significant ($P < 0.0001$).

Simple correlation coefficients of consumer sensory attributes for the *M. triceps brachii* are displayed in Table 9. Correlations between all sensory attributes are significant ($P<0.0001$). Flavor like was the sensory attribute that was the most highly correlated to overall like with an r = 0.73. Tenderness like was the attribute that exhibited the next highest correlation to overall like with an r = 0.67. Level of tenderness, level of flavor, and juiciness like each displayed r = 0.62 when correlated with overall like, and the correlation of level of juiciness and overall like was r = 0.50. When correlated with tenderness like, juiciness like and flavor like had r values of 0.59 and 0.53, respectively.

Simple correlation coefficients of consumer sensory attributes for the *M. vastus lateralis* showed a strong relationship between all sensory attributes (Table 10). All correlation coefficients presented in the table are significant ($P<0.0001$). Overall like possessed a simple correlation of r = 0.72 with both flavor like and tenderness like. When correlated with overall like, the remainder of the sensory attributes, juiciness like, level of tenderness, level of flavor, and level of juiciness, displayed r values of 0.70, 0.70, 0.61, and 0.58, respectively. Juiciness like and flavor like revealed r values of 0.60 and 0.57, respectively, when correlated with overall like.

Table 9
Simple correlation coefficients of consumer sensory attributes for *M. triceps brachii*

Variable	Level of Flavor	Flavor like	Level of Tenderness	Tenderness like	Level of Juiciness	Juiciness like
Overall like	0.62	0.73	0.62	0.67	0.50	0.62
Juiciness like	0.46	0.60	0.53	0.59	0.78	
Level of Juiciness	0.43	0.46	0.52	0.48		
Tenderness like	0.40	0.53	0.86			
Level of Tenderness	0.42	0.45				
Flavor like	0.80					

***All correlation coefficients were significant ($P < 0.0001$).

Table 10
Simple correlation coefficients of consumer sensory attributes for *M. vastus lateralis*

Variable	Level of Flavor	Flavor like	Level of Tenderness	Tenderness like	Level of Juiciness	Juiciness like
Overall like	0.61	0.72	0.70	0.72	0.58	0.70
Juiciness like	0.54	0.61	0.60	0.63	0.88	
Level of Juiciness	0.49	0.49	0.58	0.55		
Tenderness like	0.44	0.57	0.91			
Level of Tenderness	0.41	0.51				
Flavor like	0.80					

***All correlation coefficients were significant ($P < 0.0001$).

Results of the correlation between consumer sensory attributes show that tenderness, juiciness, and flavor had a strong influence on consumer satisfaction. For all seven muscles, all attributes evaluated displayed a strong positive relationship with overall like. For the *M. biceps femoris* and *M. gluteus medius*, tenderness like had the highest correlation with overall like. For the *M. infraspinatus*, *M. longissimus lumborum*, *M. rectus femoris*, and *M. triceps brachii*, flavor like was the attribute most highly correlated to overall like. For the *M. vastus lateralis*, tenderness like and flavor like were most highly correlated to overall like with the same correlation coefficients. Flavor like was found to be the attribute with the highest correlation to overall like in a consumer study on beef clod steaks (Goodson et al., 2002), and in a consumer study on beef top loin, top sirloin, and top round steaks (Neely et al., 1998). In these two studies, tenderness like was the attribute with the next highest correlation to overall like. When observing the order of influence each attribute has on overall like ratings, it appears that for different muscles different attributes are more important. For the *M. infraspinatus* and *M. rectus femoris* juiciness like was the attribute with the second highest correlation to overall like. Both flavor and juiciness like expressed high correlations to tenderness like for all muscles. This shows that flavor and juiciness can influence consumer perception of tenderness.

3.2 Warner-Bratzler Shear Force Analysis

Least squares means for cook time and cook yield were calculated (Table 11). Quality grade did not have a significant effect on cook time or cook yield ($P>0.05$). There was a significant difference between cook time and cook yield for muscle type ($P<0.0001$).

Least squares means for muscle × USDA quality grade effect for Warner-Bratzler shear (WBS) force values are presented in Table 12. The USDA Choice and Select *M. infraspinatus* had the lowest ($P<0.05$) WBS values compared to all the other muscles. These data are similar to those reported in past studies that evaluated tenderness of several beef muscles. In these studies, the *M. infraspinatus* was found to have one of the lowest ($P<0.05$) WBS of several muscles evaluated (Belew et al., 2003; McKeith, DeVol, Miles, Bechtel, & Carr, 1985). The USDA Choice and Select *M. vastus lateralis* and USDA Select *M. biceps femoris* had the highest ($P<0.05$) WBS values compared to all the other muscles. These findings are similar to McKeith et al. (1985) and Voges et al. (2007), which reported the *M. biceps femoris* (bottom round steak) to have one of the highest ($P<0.05$) WBS values. Belew et al. (2003) categorized the *M. vastus lateralis* to be intermediate in tenderness with a mean WBS of 41.9 N.

The mean WBS of the muscles evaluated ranged from 15.7 to 33.6 N. Eleven of the 14 means reported fell into the 95% confidence level established by Shackelford et al. (1991), as well as the "very tender" (WBS <31.4 N) category created by Belew et al. (2003). The remaining three means fell into the 68% confidence level established by Shackelford et al. (1991) and the "tender" (31.4 N <WBS< 38.2 N) category created by

Belew et al. (2003). All of the WBS means reported in this study are lower than the means calculated in past studies (Belew et al., 2003; McKeith et al., 1985). This difference could be the result of the muscles analyzed were cooked to lower end point temperatures as recommended by the NCBA Beef Value Cuts (NCBA, 2001) as the optimum cooking temperatures for these cuts, and all the muscles except for the *M. longissimus lumborum* were completely denuded prior to cutting into steaks.

Table 11
Least squares means for cook time (min) and cook yield (%)

	Cook time, (min)	Cook yield, (%)
Quality Grade		
Choice	15.5	79.3
Select	14.8	79.8
P-value	0.1136	0.3398
Muscle		
M. biceps femoris	18.9a	80.3b
M. gluteus medius	15.8bc	77.5d
M. infraspinatus	17.1ab	75.9d
M. longissimus lumborum	15.8bc	85.0a
M. rectus femoris	11.9d	79.7bc
M. triceps brachii	14.3c	80.9b
M. vastus lateralis	12.3d	77.6cd
P-value	<0.0001	<0.0001
RMSE	5.6303	6.7804

Means within the same column lacking a common letter (a-d) differ ($P < 0.05$).

Table 12
Least squares means for muscle × USDA quality grade effect for Warner-Bratzler shear force values (N)

Muscle	WBS (N)
Choice	
M. biceps femoris	28.1b
M. gluteus medius	20.8f
M. infraspinatus	17.9g
M. longissimus lumborum	26.9bc
M. rectus femoris	26.0bcd
M. triceps brachii	24.3de
M. vastus lateralis	33.4a
Select	
M. biceps femoris	32.1a
M. gluteus medius	26.5bcd
M. infraspinatus	15.7g
M. longissimus lumborum	24.6cde
M. rectus femoris	22.7ef
M. triceps brachii	23.6e
M. vastus lateralis	33.6a
P-value	<0.0001
RMSE	5.4504

Means lacking a common letter (a-g) differ ($P < 0.05$).

3.3 Regression Analysis of Warner-Bratzler Shear Force and Consumer Sensory

A regression analysis of WBS and consumer sensory panel tenderness like ratings was performed to generate similar 50, 68 and 95% confidence levels created by Shackelford et al. (1991). Figures 8-10 illustrate these confidence levels produced by Shackelford et al. (1991). However, the regression analysis in the present study resulted in extremely low R^2 values. Due to this low correlation between WBS and consumer tenderness like ratings, confidence levels were not established. The regression equation was plotted for each muscle with overall tenderness as a dependent variable and shear force and its squared and cubed components as independent variables. These graphs are located in Appendix A.

The figures illustrating the confidence levels generated by Shackelford et al. (1991) exhibit data points that create a negative linear slope (Figures 8-10). The data points plotted for each muscle in the present study show no linear slope due to the low R^2 value (Appendix A).

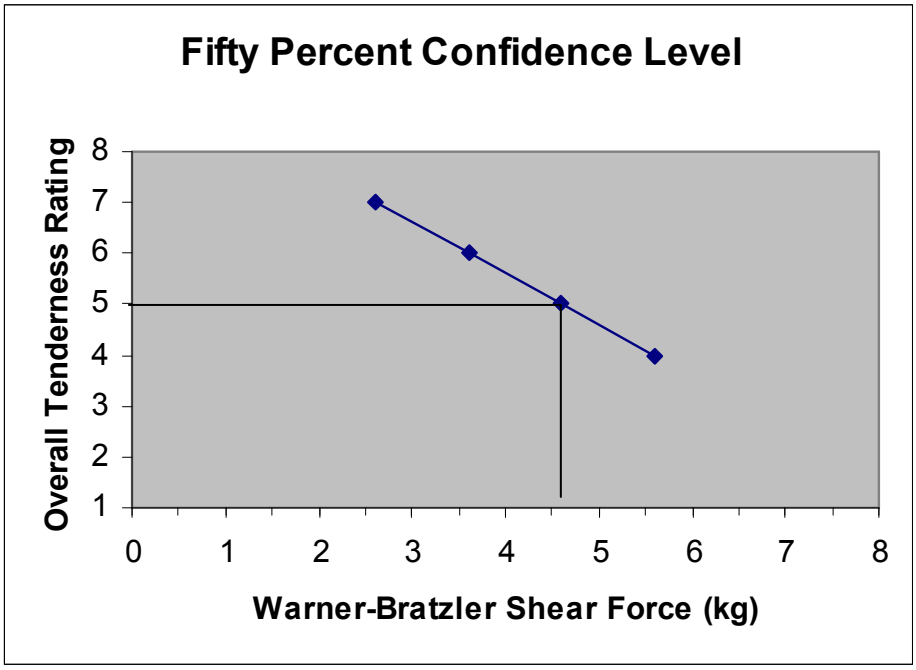

Figure 8. Warner-Bratzler shear force threshold 4.6 kg for the 50% confidence level created by Shackelford et al. (1991)

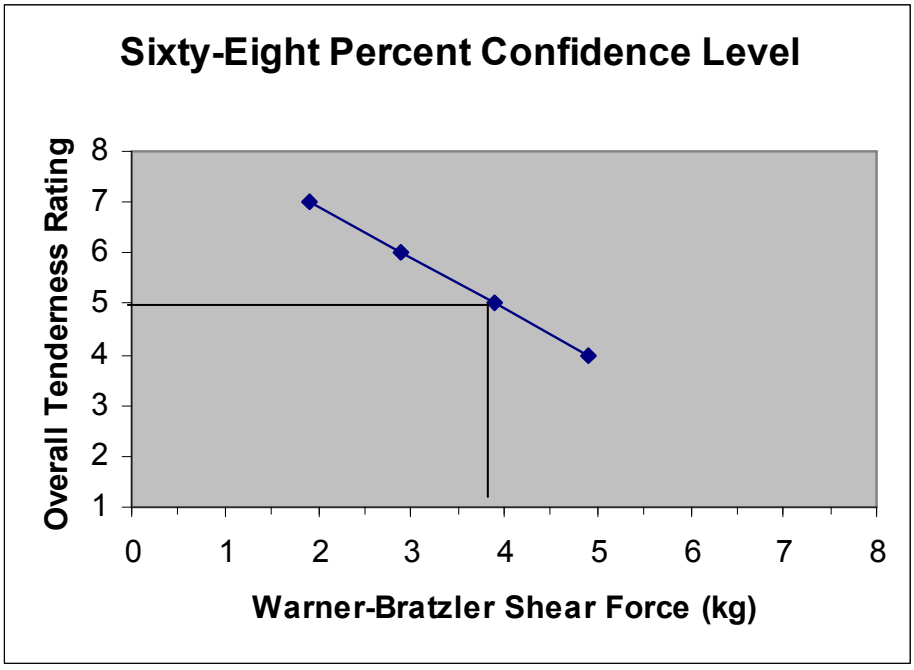

Figure 9. Warner-Bratzler shear force threshold 3.9 kg for the 68% confidence level created by Shackelford et al. (1991)

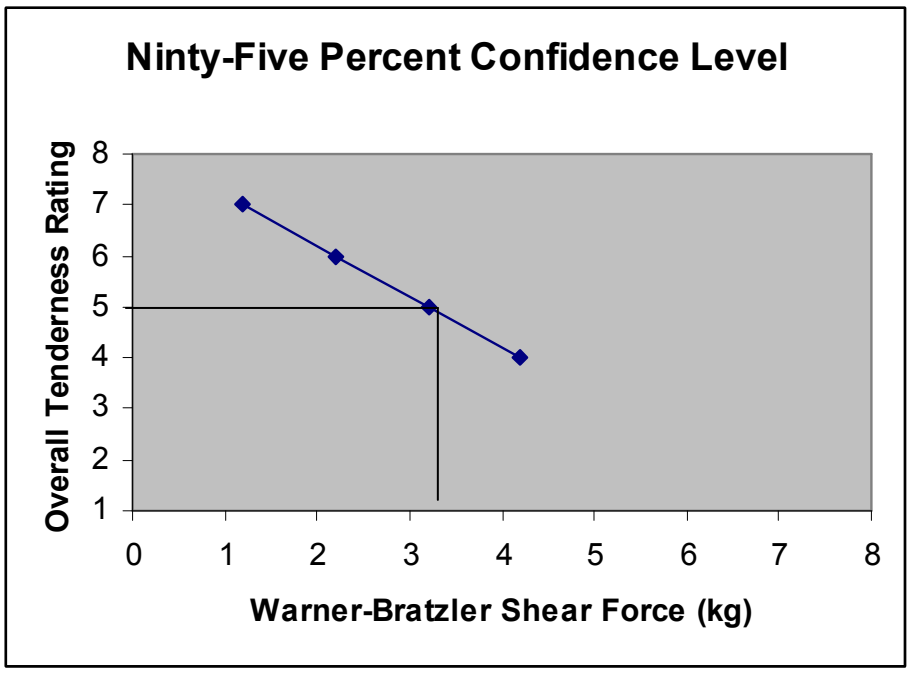

Figure 10. Warner-Bratzler shear force threshold 3.2 kg for the 95% confidence level created by Shackelford et al. (1991)

The low correlation found between WBS and consumer panel tenderness ratings could be a result of lack of variation in tenderness of steaks evaluated, as well as differences among consumer preference and scale usage. The Shackelford et al. (1991) study evaluated A and B maturity carcasses that ranged from Practically Devoid to Moderately Abundant marbling. The study evaluated steaks with a wide variation in tenderness. The current study evaluated muscles of USDA Choice and Select quality grade which resulted in much less tenderness variation of the steaks analyzed. By observing the data points plotted in Appendix A, it is apparent that the consumer tenderness ratings vary greatly for all WBS values. Samples that would be considered "very tender" according to Belew et al. (2003) received ratings of 1 (extremely dislike) for tenderness like. This could be due to the difference in individual consumer preference or consumer's experience with consumption of beef. Goodson et al. (2002) found that consumers who were heavy beef eaters rated samples higher in overall like compared to consumers who split consumption between all types of meat. Based on the WBS values the majority of the steaks evaluated were considered "tender" or "very tender" (Belew et al., 2003), which may have caused consumers to focus on other attributes when evaluating these samples. Inadequate flavor or juiciness may have caused the consumers to rate the samples lower for tenderness like.

The majority of the steaks evaluated fell into the 95% confidence level created by Shackelford et al. (1991) (Table 13). All of the *M. infraspinatus* steaks evaluated in this study met the WBS requirement (WBS<31.4 N) for the 95% confidence level. More than 92% of the *M. gluteus medius*, *M. longissimus lumborum*, *M. rectus femoris*, and *M.*

triceps brachii met the WBS requirements for the 95% confidence level. As the confidence level increased a higher percentage of steaks met the shear requirement for each category.

Consumer tenderness like ratings were categorized by 1 through 4, 5 and 6, and 7 and 8 for each muscle. Within each muscle, the mean plus or minus one standard deviation for each of these three categories was displayed in bar graphs (Appendix B). The expected trend for these graphs would be for the WBS mean and standard deviation to increase as the tenderness like ratings decreased. The *M. longissimus lumborum*, *M. rectus femoris*, and *M. vastus lateralis* are the only muscles that displayed a trend similar to what would be expected for the WBS of each category. These muscles exhibited mean WBS values which increased as the tenderness like ratings decreased.

Table 13
Percentage distribution of muscles that are expected to be rated "slightly tender" or higher for overall tenderness using 50, 68 and 95% confidence levels established by Shackelford et al. (1991)

	Confidence Level		
Muscle	95%	68%	50%
M. biceps femoris	65.0	83.8	92.5
M. gluteus medius	92.5	98.8	98.8
M. infraspinatus	100.0	100.0	100.0
M. longissimus dorsi	92.5	98.8	98.8
M. rectus femoris	93.8	98.8	100.0
M. triceps brachii	92.4	100.0	100.0
M. vastus lateralis	40.0	82.5	96.3

CHAPTER IV

CONCLUSIONS

Based on the Warner-Bratzler shear and consumer sensory analysis, there may be muscle-specific WBS threshold levels for tenderness. However, these values may be more difficult to find than originally thought. There may be more that goes into determining threshold levels than observing WBS and consumer tenderness like ratings. Individual consumer preference makes it difficult to identify one acceptable WBS threshold that will satisfy all consumers. Other sensory attributes such as flavor and juiciness have an influence on tenderness like and overall like. After reaching a certain point in tenderness, these attributes may be more important in determining acceptability of beef steaks.

Additional research should be conducted on individual beef muscles to determine whether different WBS thresholds really exist. Identification of these thresholds will allow the industry to reduce variation of beef tenderness, as well as market beef according to tenderness.

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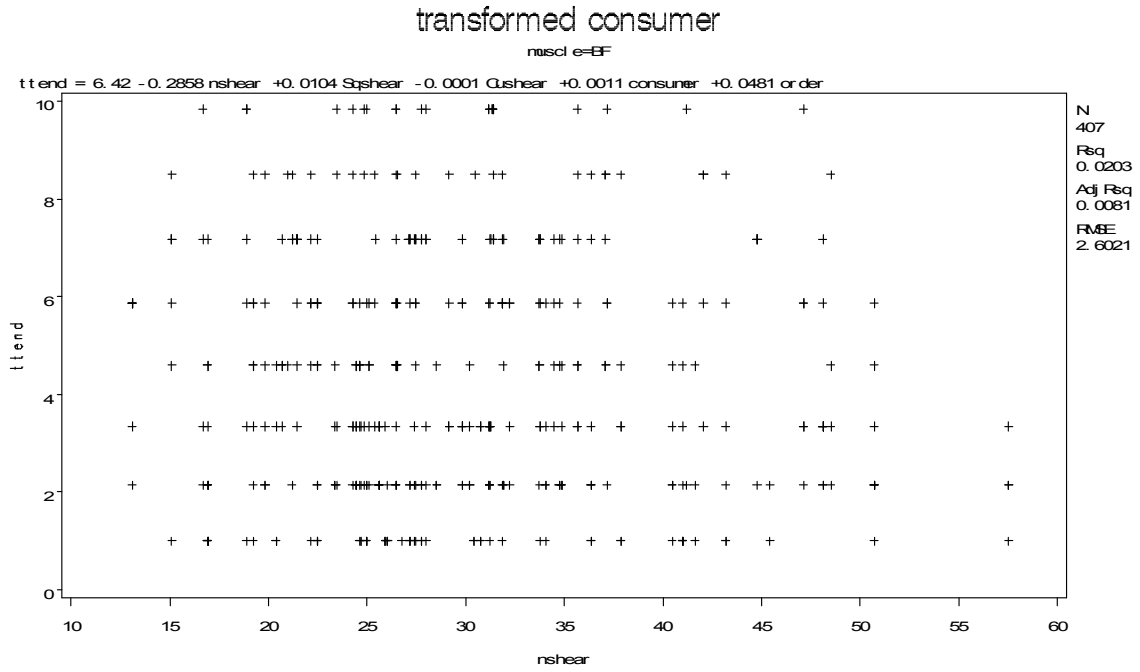
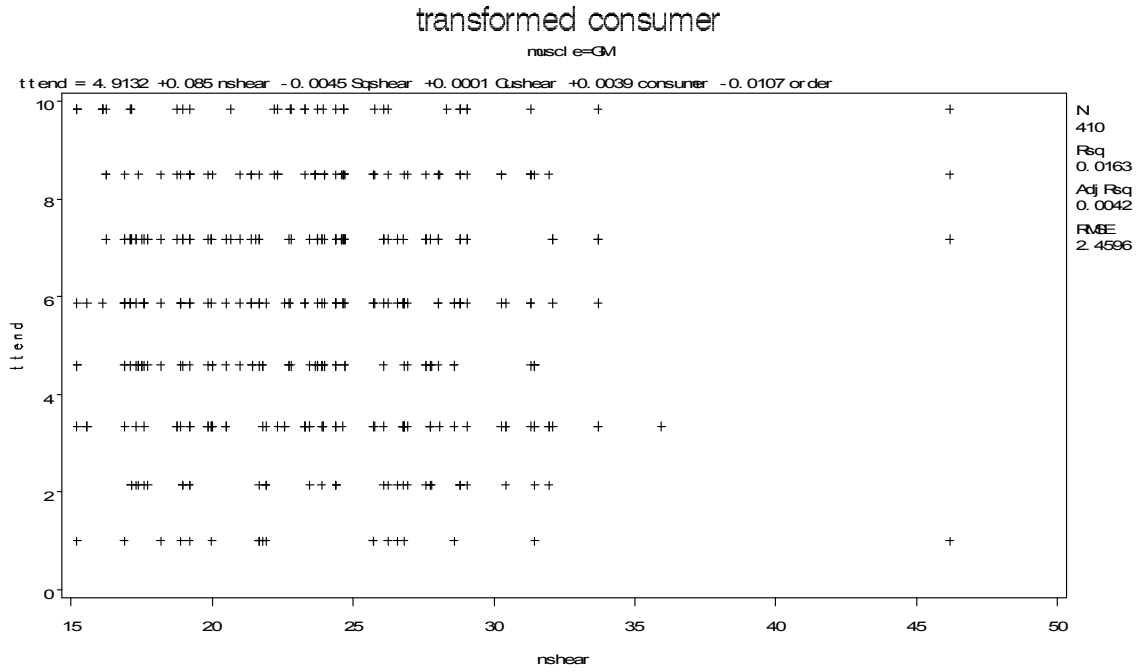
APPENDIX A

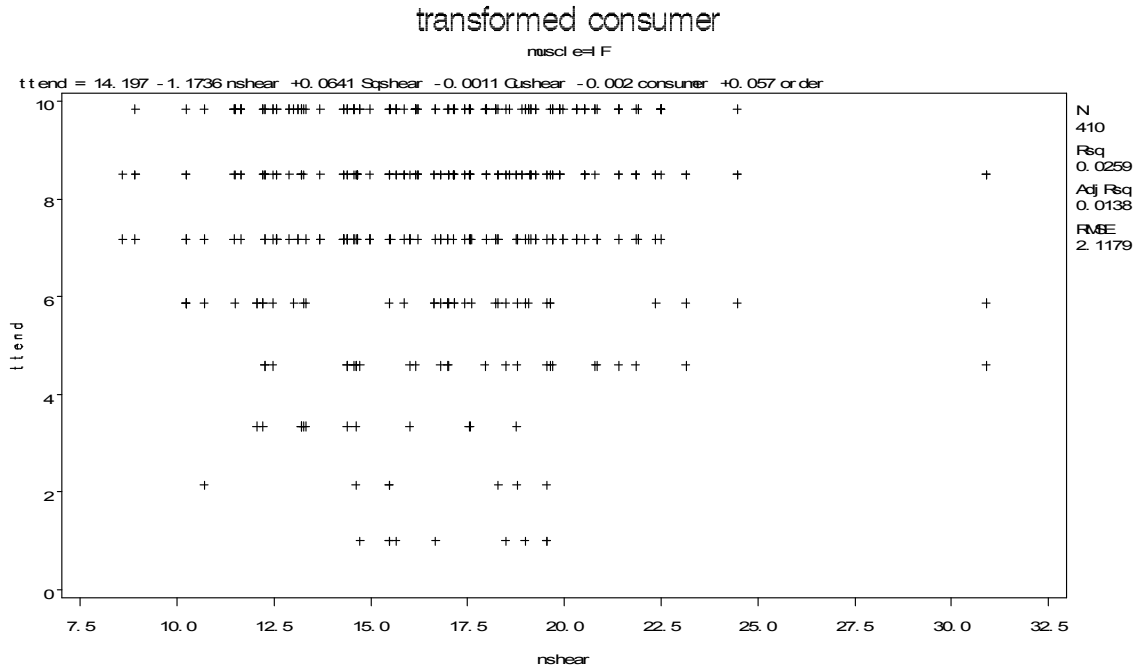
REGRESSION EQUATION PLOTS



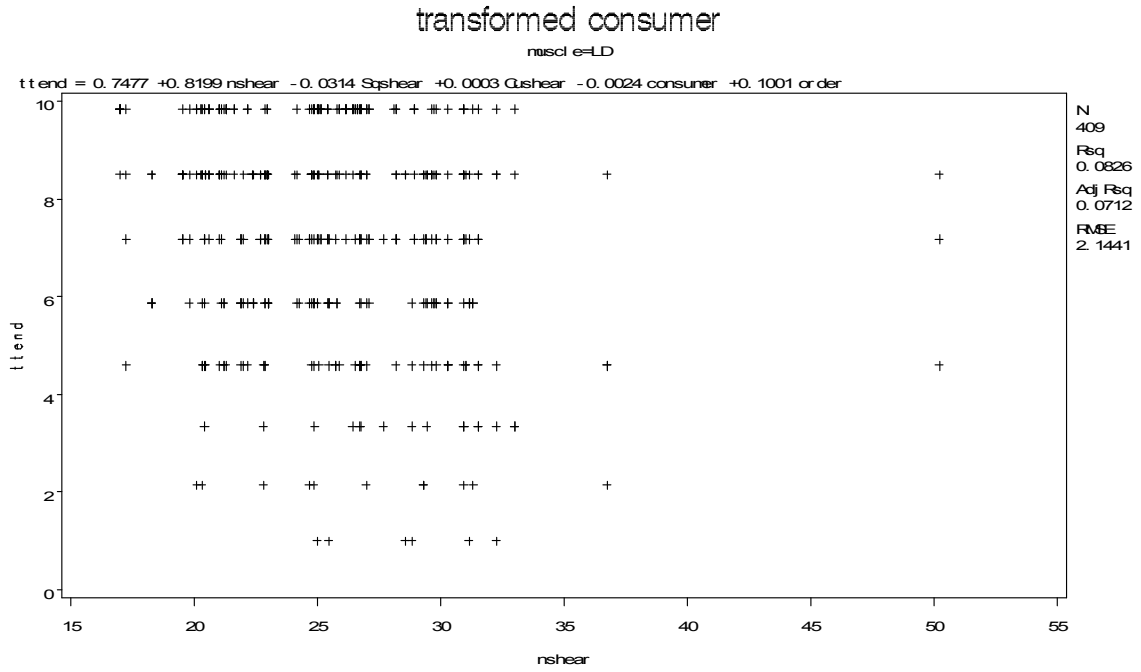
A-1 Plot of regression equation for overall tenderness like ratings and WBS for *M. biceps femoris*



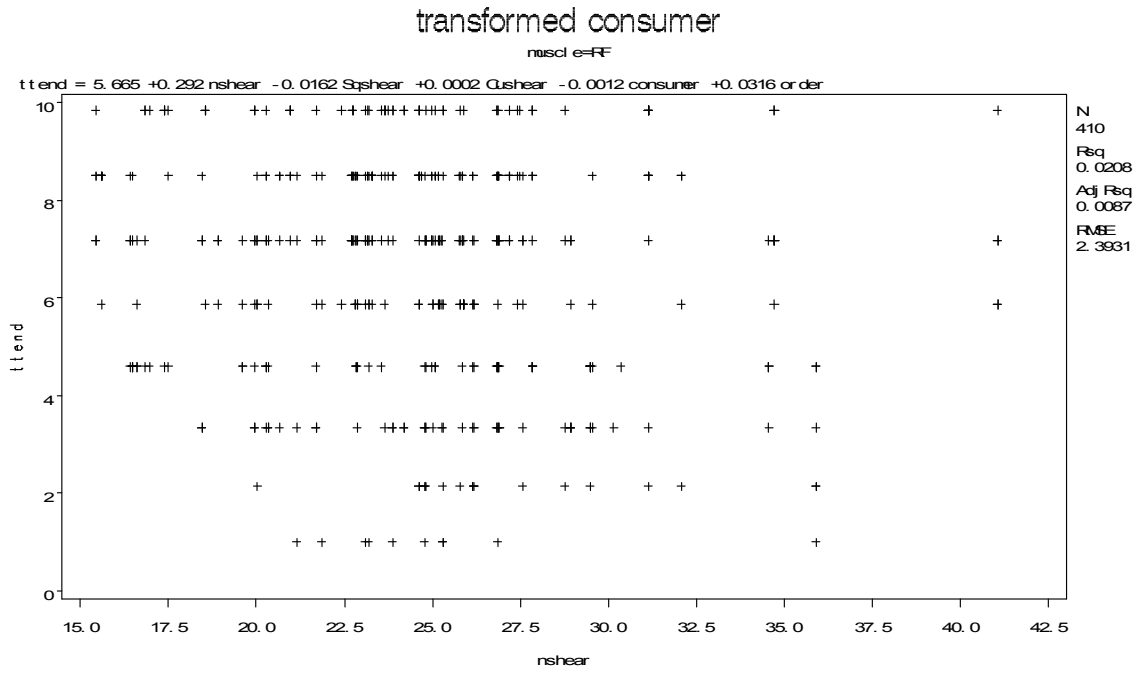
A-2 Plot of regression equation for overall tenderness like ratings and WBS for *M. gluteus medius*



A-3 Plot of regression equation for overall tenderness like ratings and WBS for *M. infraspinatus*

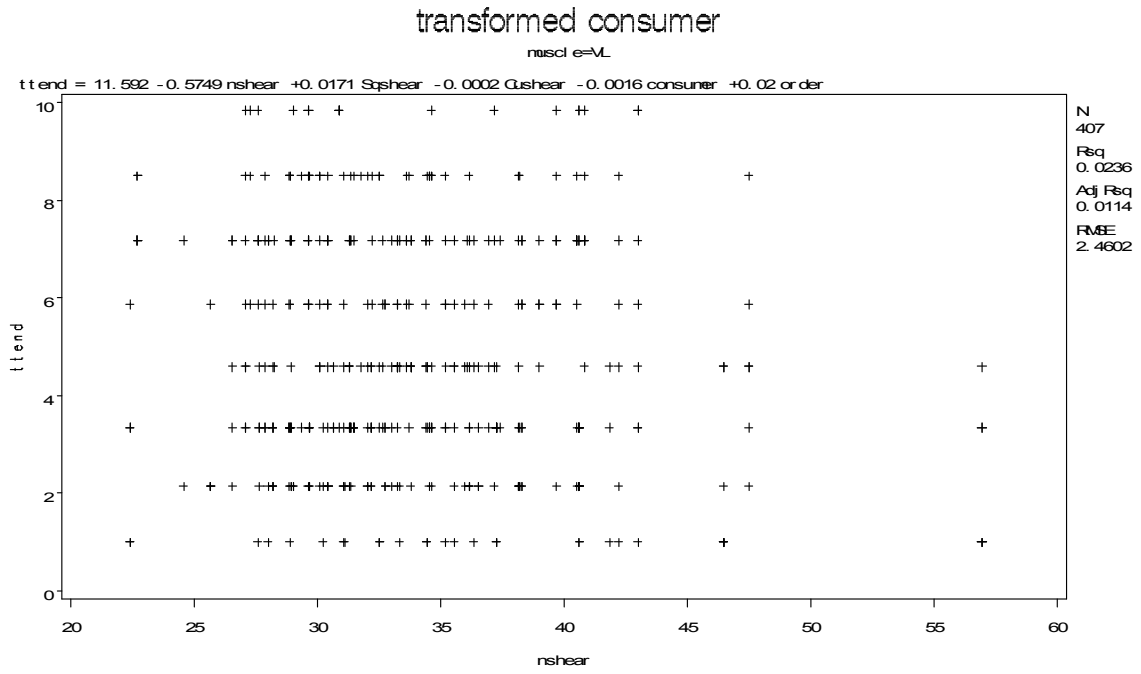


A-4 Plot of regression equation for overall tenderness like ratings and WBS for *M. longissimus lumborum*



A-5 Plot of regression equation for overall tenderness like ratings and WBS for *M. rectus femoris*

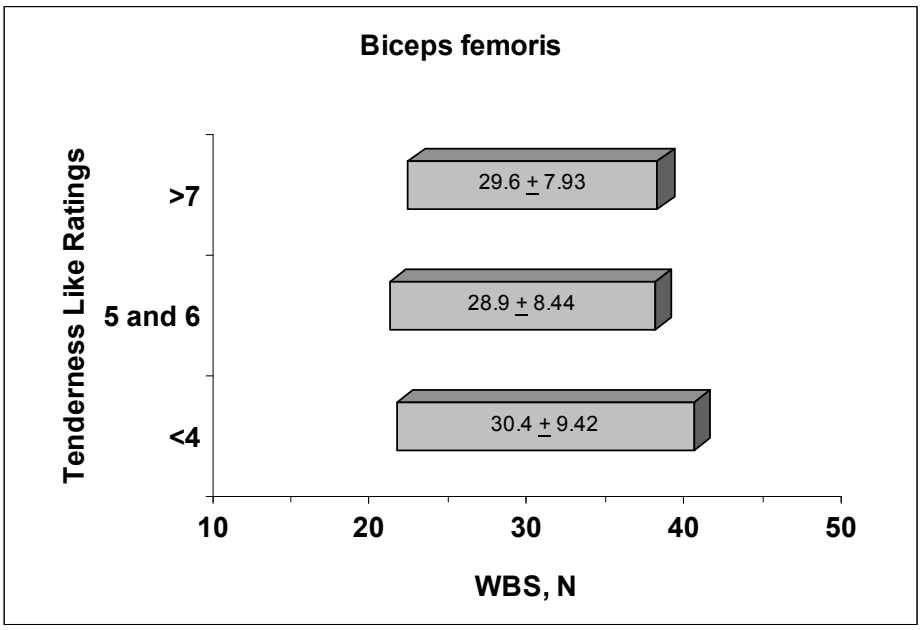
A-6 Plot of regression equation for overall tenderness like ratings and WBS for *M. triceps brachii*



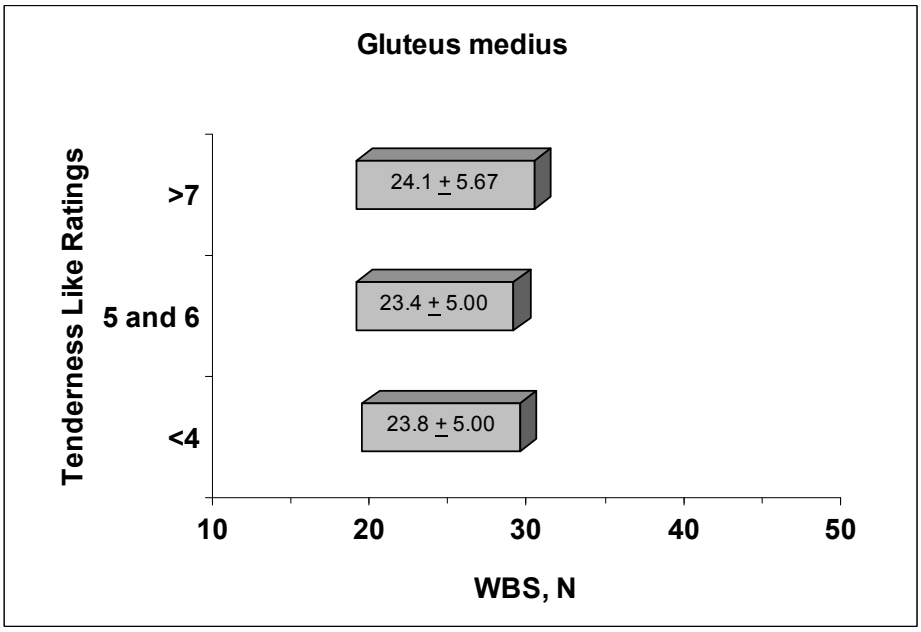
A-7 Plot of regression equation for overall tenderness like ratings and WBS for *M. vastus lateralis*

APPENDIX B

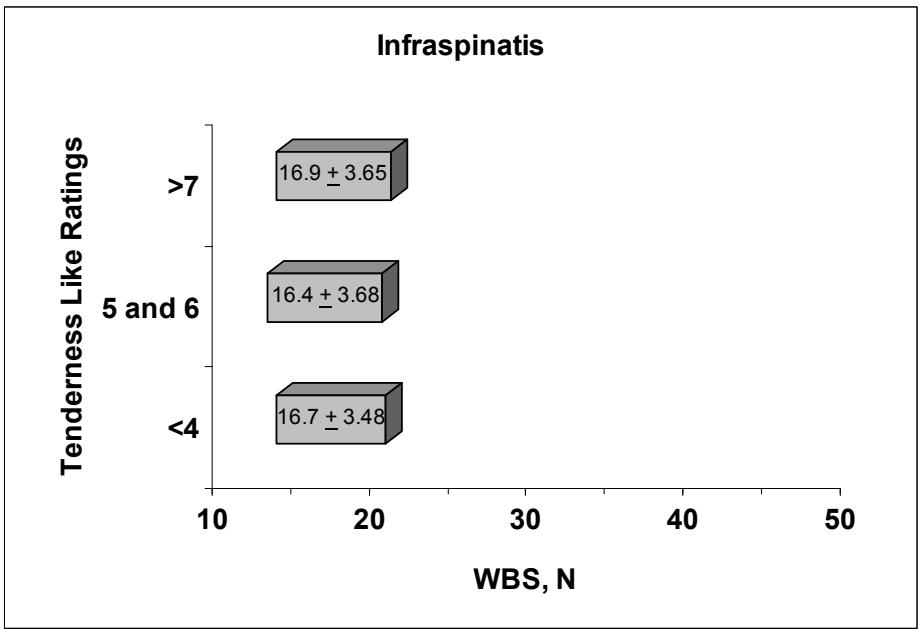
WBS AND TENDERNESS RATING GRAPHS



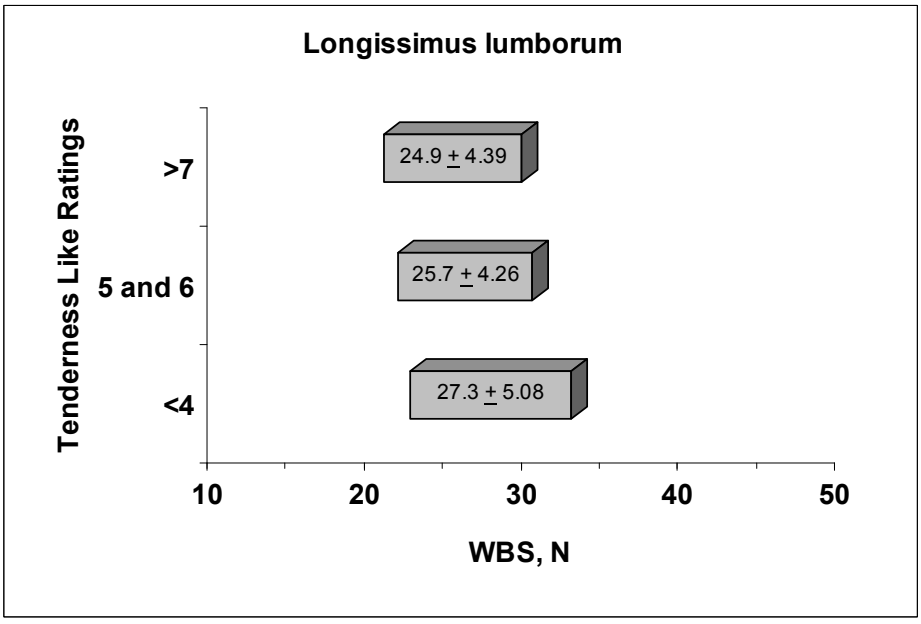
B-1 WBS mean plus or minus one standard deviation for tenderness like rating categories of <4, 5 and 6, and >7 for *M. biceps femoris*.



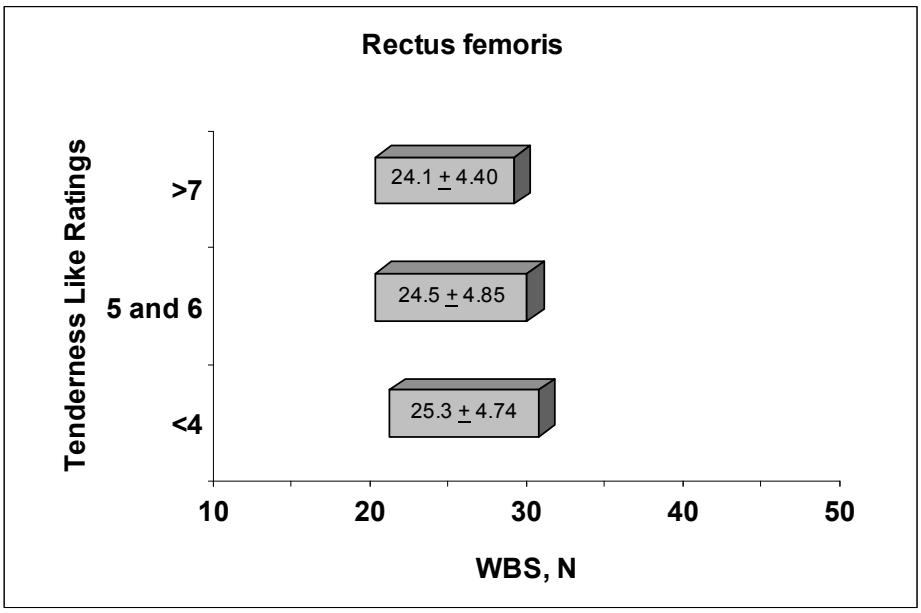
B-2 WBS mean plus or minus one standard deviation for tenderness like rating categories of <4, 5 and 6, and >7 for *M. gluteus medius.*



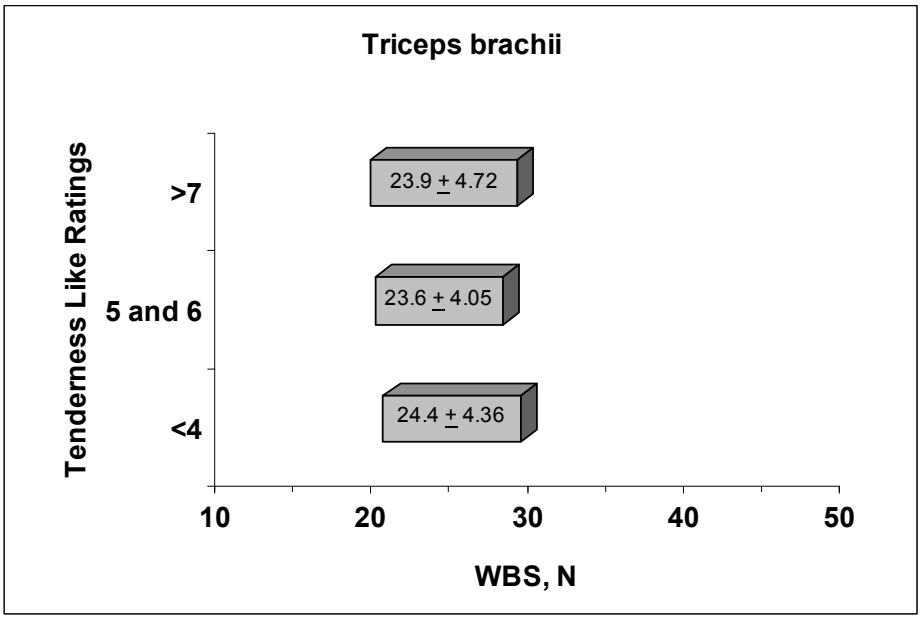
B-3 WBS mean plus or minus one standard deviation for tenderness like rating categories of <4, 5 and 6, and >7 for *M. infraspinais.*



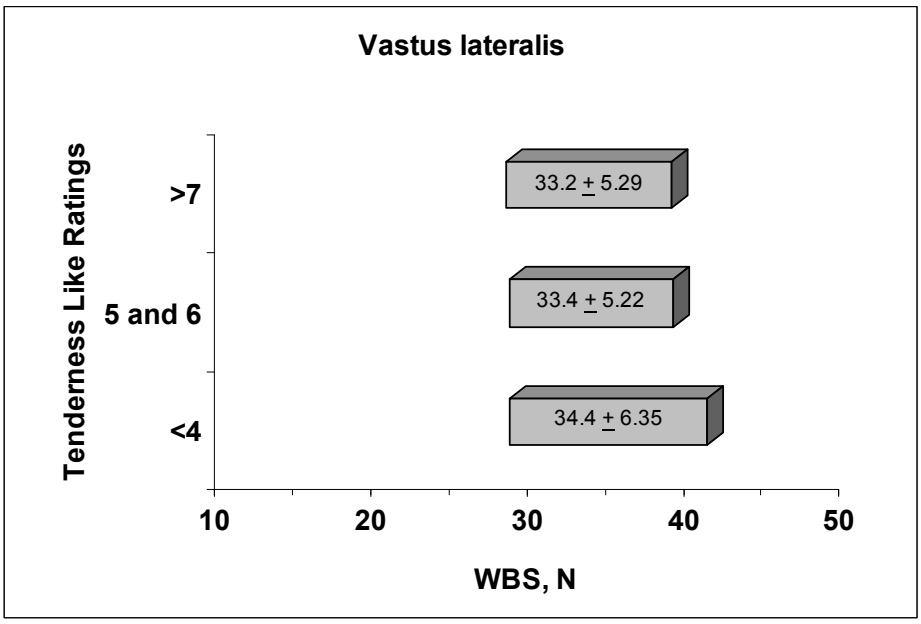
B-4 WBS mean plus or minus one standard deviation for tenderness like rating categories of <4, 5 and 6, and >7 for *M. longissimus lumborum.*



B-5 WBS mean plus or minus one standard deviation for tenderness like rating categories of <4, 5 and 6, and >7 for *M. rectus femoris.*



B-6 WBS mean plus or minus one standard deviation for tenderness like rating categories of <4, 5 and 6, and >7 for *M. triceps brachii.*



B-7 WBS mean plus or minus one standard deviation for tenderness like rating categories of <4, 5 and 6, and >7 for *M. vastus lateralis.*

VITA

Name: LeeAnn Sitka

Hometown: Hallettsville, Texas

Education: Texas A&M University
B.S., Animal Science
May 2005

Texas A&M University
M.S., Animal Science (with an emphasis in meat science)
August 2007

Address: 2471 TAMU
College Station, TX 77843